Stable isotope constraints on the transport of water to the Andes between 20° and 30°S during the last glacial cycle.

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Many enclosed basins in the arid Altiplano of Chile, Argentina and Bolivia contain thick evaporite sequences and can be used to extract a history of climate change. Two halite cores from the salars of Atacama and Hombre Muerto show that perennial saline lakes have existed during the past in areas that are now hyper-arid and where lakes are desiccated. The climate records from these cores cover the last glacial cycle for the desert of N Chile and NW Argentina, respectively. Information on hydrologic balances, temperature and stable isotope compositions of the paleolake waters trapped in inclusions yield past meteorologic conditions. The lack of shorelines indicate that the lakes that existed were never deep. The cores were dated by U-series and accumulation rates vary between 0.5 m/kyr and 0.9 m/kyr. The hydrologic budget histories recorded at both sites are similar on a first order scale: lakes of various sizes existed repeatedly prior to 10 ka, and both lakes have been almost dry since 10 ka. On a second order scale there are differences between the lakes at the two sites, such as size and permanence. This paper focuses on another measure of differences between sites and between lakes of varying ages: isotopic composition of lake water reflects differences in the sizes of the lake, relative humidity and isotopic composition of the meteoric water sources. We suggest a model linking middle and late Quaternary moisture history patterns to heat transfer in the South Atlantic.

Salar de Atacama

The majority of precipitation at the salar falls during the austral summer. Storms that produce rain over N Chile have trajectories that show that the air masses providing moisture are derived from the Amazon; storms that have air masses from the Pacific produce no rain. Infrequent winter rain/snow is produced from interaction of polar fronts with tropical air from the Amazon, but it is described that winter snows ablate and do not contribute to groundwater. The majority of water enters the salar through aquifers that flow from the high elevation (5000 m+) volcanic peaks to the east of the salar, a smaller volume of water flows through the Rio San Pedro and Rio Vilama that enter the salar in the north. The $\delta^{18}O$ of freshwater wells in the eastern alluvial fans is between -7 and -8 ‰ and lies close to the LMWL. Snow samples collected from the Andean Cordillera immediately to the east of the salar have $\delta^{18}O$ compositions between -9 and -13 ‰. Surface waters show considerable isotopic enrichment. We use a model describing the evaporative enrichment to estimate relative humidity, to estimate the isotopic compositions ($\delta^{18}O$ and δD) of meteoric water sources prior to evaporation, and to estimate the isotopic compositions of atmospheric water vapor.

Lakes were especially common during the interval between 53 ka and 16.5 ka (OIS 3 and 2), and the largest, most established lake existed between 26 and 19 ka. The stable isotope composition of lake waters from the fluid inclusions form an array that is not distinguishable from the modern evaporation array described by surface waters. Models of these paleolake waters indicate that that the isotopic composition of meteoric water and atmospheric water vapor has not changed much over the last 60 ka.

Salar de Hombre Muerto

Rainfall at the salar occurs during the austral summer. The air masses that produce most of the rain originate from the tropical Atlantic and cross the Amazon, but the salar is close to the

boundary between this rainfall domain and the rainfall domain of the South Atlantic Convergence Zone (SACZ). The vast majority of the water reaching the salar today does so by the Rio de los Patos, a stream that rises on Cerro Galan to the south. The isotopic composition of this stream is variable on annual timescales; however, for all years that have been analyzed, it is isotopically heavier than more locally derived streams despite rising at higher elevations. Some years the stream also has very high deuterium excess (>+40), suggesting that the stream water has been recycled through the atmosphere in arid conditions to a greater or lesser extent every year. The evaporative enrichment of water in the Rio de los Patos has also been modelled to give an estimate of the isotopic composition of atmospheric water vapor and humidity (the latter agreeing with measurements at the salar).

The results of sedimentary and petrographic analyses on a 40 m long core show that during the last 80 kyr, there have been numerous lakes in the now-dry salar. Each lake in this succession was either shallower or more ephemeral the previous lake interval. The lake waters trapped in the fluid inclusions are variable. Those from the lake that existed between 24 and 20 ka are not dissimilar to modern surface waters; lake waters between 82 and 38 ka are less variable and plot much closer to the meteoric water line. The fluid inclusion data have been modelled and while the 24-20 ka lake has inflow waters and an atmospheric water vapor composition much like the modern system, the lakes between 82 and 38 ka have isotopically depleted inflow waters, and not as extreme d_{xs} while the atmospheric water vapor has similar isotopic composition. The isotopic depletion of the inflow waters cannot be due to lower temperatures as the temperature drop is unrealistically large and is not compatible with fluid inclusion homogenization temperatures from the same core, or with any other temperature record in South America. The inflow water to the 82-38 ka lakes at Hombre Muerto is similar to glacial snow from (>5500 m elevation) peaks in Bolivia and Peru. However, the 82-38 ka moisture that reached Hombre Muerto could not have come from the source of today's Peru – Bolivia moisture (tropical Atlantic-Amazon), because the Andean regions north of Hombre Muerto were dry at that time.

The climate records thus obtained are not the same for the two salars. At Atacama, the historical sequence of saline lakes is similar to lake level highstands in the central Andes. In addition, the largest deepest lake coincided with the northern hemisphere LGM. Meteoric water sources are currently the tropical Atlantic via the Amazon Basin, and the same source of water is indicated for the lakes in the past. At Hombre Muerto, the climate history is different. The lakes that have periodically occupied the salar have become progressively smaller through time - that is to say the largest lakes occurred during MOIS 4 and early MOIS 3 and the smallest during MOIS 2. Water recycling through the atmosphere by evaporation-condensation is common today as it was during the time the MOIS 2 lake existed, but was not during MOIS 4 & 3.

Synoptic conditions that bring moisture to dry areas south of the central Andes, and that brings dry air to the Amazon Basin and central Andes involves a westward enhancement of the S Atlantic high and intensification and westward shift of the South Atlantic Convergence Zone. Analogous Quaternary changes in the intensity and meridional direction of the NE and SE trades is well documented and occurs with precessional periodicity, as does the structure of the water column in the western equatorial Atlantic. The timing of stronger trade winds and thickening of the warm water pool in the west-equatorial Atlantic occurs, within our stratigraphic model, at the same time as the biggest lakes at Hombre Muerto. We speculate that either temperature contrasts between the continent and South Atlantic sea surface and/or a shift in the South Atlantic high due to changes in the trade winds are responsible for the transport of water onto the continent, and the regional climate that results.